

Clinical Spotlight

A CLINICAL CASE/DENTAL TOPIC CONTRIBUTED BY PENN DENTAL MEDICINE FACULTY

Ceramic Printing

A Comparative Study of the Physical Properties of 3D-Printed and Milled High Performance Ceramics

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Introduction

The fabrication of dental restorations has substantially changed in the past decade. Two major events in the advancement of dental prostheses manufacturing were the development of CAD-CAM technology and the introduction of “all ceramic” materials. “All ceramic” materials for dental restorations mimic very naturally the optical properties of teeth. In addition to this, some of them, like zirconia, present good mechanical properties and can be used as monolithic materials, avoiding the need of facial veneering and porcelain chipping without compromising esthetics or long-term physical stability of the restoration. However, CAD-CAM technology is a subtractive manufacturing technique, which means it involves removing sections of a large zirconia block by machining or cutting it away until the designed shape remains. According to previous reports, approximately 90% of the prefabricated block is wasted during this process. Furthermore, the dimensions of a restoration are defined by the available block size and can be limited. In an attempt to overcome those main disadvantages, additive manufacturing was developed several years ago. Additive manufacturing, better known as 3D-printing is a additive production technique that has been applied to dentistry for the fabrication of surgical guides, dental casts, bite splints and recently for the fabrication of complete dentures. Those devices are mostly printed out of a variety of resin-based materials. With the advances in material development and refinement in 3D-printing technology, the possibility to print restorations out of all ceramic materials now becomes available. It can open up tremendous opportunities not just for the design and fabrication of dental restorations; even customized bone grafts, implants and scaffolds for tissue regeneration can be fabricated. In regards to dental prostheses manufacturing, the printing of “all ceramic” materials is yet to be explored and only limited research has been conducted in this field.

Rationale

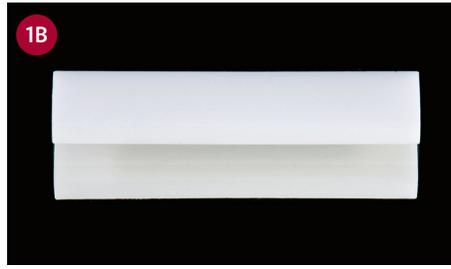
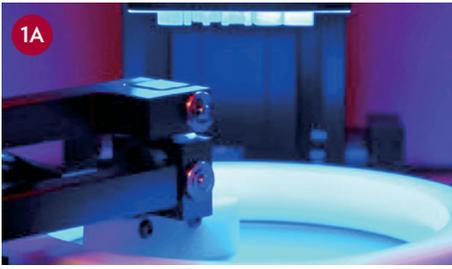
Three-dimensional printing of zirconia is a potentially advantageous production method for medical and dental applications.

The aims of this study were:

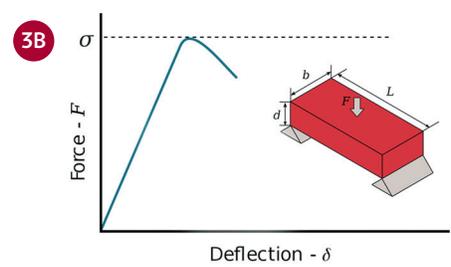
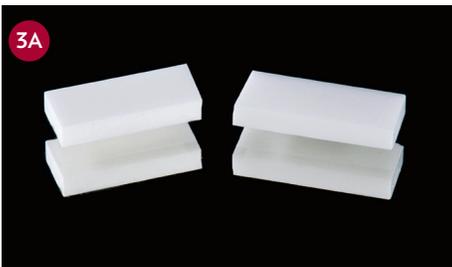
1. To compare the flexural strength of 3D-printed full-contour zirconia to milled high performance isostatic pressed zirconia ceramics.
2. To determine the effect of thermal and mechanical load cycling on the flexural strength of a 3D-printed zirconia ceramic.

Materials and Methods

Rectangular bars of 3D-printed (**Image 1A**) FCZ ceramic LithaCon 3Y 230 ceramic (Lithoz, Austria), of dimensions: 25 mm x 5 mm x 2 mm (**Image 1B**) and milled high performance isostatic pressed zirconia (**Image 1C**) Prettau Zirkonia ceramic (Zirkonzahn, Italy) were fabricated according to manufacturer’s instructions. Flexural strength of the two ceramics was determined using an Instron Testing Machine at a crosshead speed of 1mm/min. (Instron 4204, Norwood, MA, USA.) following ISO 6872. Bars of 3D-printed FCZ ceramic LithaCon 3Y 230 ceramic (N=10) were subjected to 40,000 thermal cycles in a thermocycling machine (SD Mechatronic GMBH, Feldkirchen-Westerham, Germany). Thermocycling (**Image 2A**) was performed at 5°C and 55°C with a dwell time of 30 seconds. The same number of bars of 3D-printed FCZ ceramic LithaCon 3Y 230 ceramic were subjected to thermomechanical loading cycles (**Image 2B**) in a chewing simulator (SD Mechatronic CS-4) for 960,000 cycles at 37°C and 10 bars served as controls. Flexural strength of thermocycled and thermomechanically load cycled printed zirconia was determined as described above (**Image 3A, 3B, 3C**). The data was compared using ANOVA and Holm Sidak post hoc analysis.



Thermocycling was performed at 5°C and 55°C with a dwell time of 30 seconds.



3C. Equation to Calculate Flexural Strength.

$$\sigma = \frac{3FL}{2bd^2}$$

1A. 3D Ceramic Printer with LMC Technology. 1B. 3D-Printed Zirconia Bar out of LithaCon 3Y 230 ceramic. 1C. Milled Zirconia Bar out of Isostatic Pressed Material. 2A. Thermo Cycling of the 3D-Printed Samples. 40,000 Cycles simulate 4 Years. 2B. Load Cycling of the 3D-Printed Zirconia Samples. 960,000 Cycles simulate 4 Years. 3A. Fractured 3D-Printed Zirconia Sample. 3B. 3 Point Flexural Strength Test. 3C. Equation to Calculate Flexural Strength.

Results

Flexural strength values for the 3D-printed FCZ were 855.4 (112.6) MPa for untreated samples and 1014.4 (123.9) MPa for isostatic pressed zirconia samples. There were no statistically significant differences ($p > 0.05$) in flexural strength between milled FCZ and printed FCZ (Chart 1). For printed zirconia, flexural strength for untreated zirconia was not significantly different from thermo cycled samples (779.8 (136.8) MPa) or thermo mechanical load cycled samples (888.4 (59.3) MPa) ($p > 0.05$) (Chart 2).

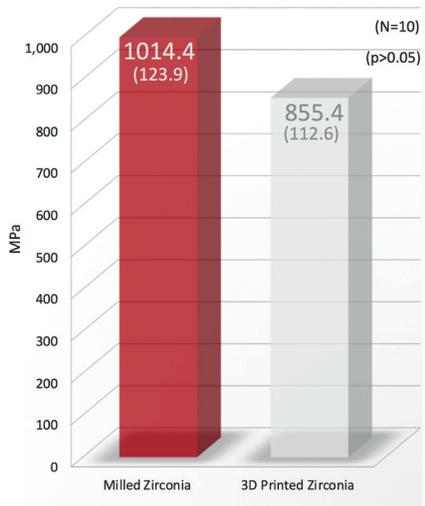


CHART 1. Flexural Strength Values of the Untreated Milled and 3D-Printed Zirconia.

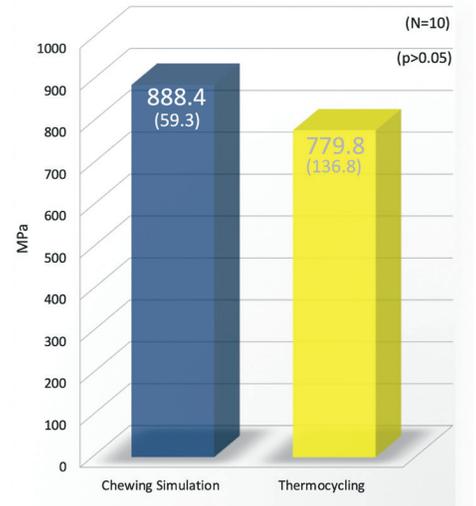


CHART 2. Flexural Strength Values for Treated 3D-Printed Zirconia.



4A. First Results of 3D Printed Zirconia Crowns. **4B.** Digital Design of a Scaffold with 0.03mm Pore Size. **4C.** Customized 3D Printed Scaffold out of TriCalcium Phosphate. **4D.** Customized 3D Printed Zirconia Implant.

Conclusion

The flexural strength of printed zirconia is comparable to the milled zirconia ceramic Prettau Zirkon. Thermo cycling and load cycling did not significantly reduce the flexural strength of 3D-printed LithaCon 3Y 230 ceramic. Our results point out that mechanical properties of printed and milled zirconia may be comparable, and, even though more research is needed, ceramic 3D-printing emerges as a promising method for the manufacturing of zirconia for dental applications.

Clinical Significance

3D-printing technology allows fabrication of extremely complex geometric shapes and has the potential to address limitations associated with milling of zirconia and expand its applications in medicine and dentistry (Image 4A, 4B, 4C, 4D).

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Internationally recognized in the area of esthetic ceramic restorations and CAD/CAM-technology, Michael Bergler, MDT, is co-founder of the CAD/CAM Ceramic Center at Penn Dental Medicine. He has published and lectured extensively on restorative materials and dental and digital technology. An active member of the International Academy for Digital Dental Medicine, he is also Section Editor of Current Health Reports for *Modern Production Laboratory Advances in Dental Technology*, Springer Nature, and on the editorial board of the *International Journal of Prosthodontics*, Quintessence Publishing Co, Inc. He trained in Germany at the University of Erlangen-Nuremberg, Dept. of Prosthodontics, and earned his Certificate of Master Dental Technician (MDT) at the Masterschool of Freiburg, Germany. Serving on the teaching faculty for the Master of Science in Oral Implantology program at University of Erlangen-Nuremberg, he also held numerous appointments within the Dept. of Prosthodontics at the School of Dentistry, University of Erlangen-Nuremberg, while also serving as a MDT with Dental Laboratory Rainer Semsch, Freiburg im Breisgau, Germany. His dental laboratory training has included study under Kazunobu Yamada, CUSP Dental Laboratory, Nagoya City, Japan; Hitoshi Aoshima, Pearl Laboratory, Tokyo, Japan; and Dr. Gerard Chiche, Chairman of Prosthodontics, Louisiana State University School of Dentistry, New Orleans, La.